
Energy Research at Lawrence Livermore National Laboratory

*Developing technologies to
benefit the economy, the
environment, and national
security*

Excerpts from the Energy Directorate's
Submittal to the Institutional Plan FY 1996-2001

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Summary

Our Mission

We bring the strengths of Lawrence Livermore National Laboratory to bear on the development of energy source and use technologies that are attractive by the criteria of security, economics, safety, and environmental impact. We work with U.S. industry to commercialize these technologies. We influence and support national policies in the energy arena, and we address energy issues that are beyond the normal planning horizon of industry.

How We're Organized

There are four programs within the Laboratory's Energy Directorate.

- ***Magnetic Fusion Energy***

The MFE program is a strong player in the international development of a fusion reactor that will be an economical, safe, and environmentally benign source of electric power for the twenty-first century.

- ***Fission Energy and Systems Safety Program***

The FESSP applies the Laboratory's multidisciplinary engineering and scientific capabilities to all aspects of fission energy. FESSP works with various government agencies that are concerned with nuclear and nonnuclear facilities.

- ***Energy, Manufacturing, and Transportation Technologies***

The EMATT program adapts existing technologies and develops new technologies to solve problems in the broad area of economic competitiveness. Much of our work is done in partnership with U.S. industry or other organizations.

- ***Energy Analysis, Policy, and Planning***

The EAPP program defines the context in which energy work at LLNL should take place, suggests and initiates new program directions, and provides a rationale for technologies we choose to advance.

We Have Many Funding Sources

As the descriptions of our projects indicate, our work is funded by a range of sponsors, including many programs within the U.S. Department of Energy and a number of other federal and state agencies.

We Work in Collaboration and Partnerships

Finding ecological and economic solutions to the world's energy problems requires the coordinated effort of many organizations. In our research, we are collaborating with other national laboratories and government agencies, with U.S. industry large and small, with academia, and with international partners. For example, the Energy Directorate is responsible for about one-third of LLNL's Cooperative Research and Development Agreements (CRADAs) with industrial partners.

The Energy Directorate: Vision, Goals, and Strategies

Magnetic Fusion Energy

Situation

Magnetic fusion worldwide has shown steady scientific progress during the past 15 to 20 years, with the key confinement parameter approximately doubling annually; it is preparing to enter the burning-plasma regime. The national goal is to demonstrate a power reactor that would begin operating about 2025. In 1991, the Secretary's Fusion Policy Advisory Committee advanced a program plan and budget consistent with this goal. The plan relies heavily on international cooperation. The overall focus at LLNL is to advance this goal by improving the tokamak concept and exploring innovative magnetic fusion energy concepts.

Vision

A baseline fusion energy electric power source that is attractive by the criteria of economics, safety, and the environment.

Goal

To advance our vision of fusion electric power through improving existing concepts, especially the tokamak, and identifying and evaluating alternative reactor concepts.

Issues

To address our goal, we seek to:

- Improve the tokamak to optimize reactor economics and attractiveness.
- Develop comprehensive computational models to evaluate fusion concepts.
- Identify alternative fusion approaches leading to attractive power plants with qualitative improvements over presently projected reactor costs, safety, and environmental impacts.

- Strengthen international cooperation in magnetic fusion energy to share the cost and technical risks of large-scale fusion devices.

Strategies

- Participate in experiments on the DIII-D tokamak at General Atomics to strengthen the physics and technology of magnetic fusion reactors and, through innovative experiments, improve the tokamak.
- Participate in the design and construction of, and experiments on, the Tokamak Physics Experiment (TPX) at Princeton University.
- Develop comprehensive computational tools for modeling fusion plasmas in a large-scale, integrated manner.
- Explore innovative magnetic fusion energy concepts using theory and numerical modeling, experiments, and exploratory reactor designs.
- Participate in the engineering design and R&D of the International Thermonuclear Experimental Reactor (ITER) being designed to demonstrate long-pulse ignition and nuclear testing.

Success Indicators

- Experimental demonstration on DIII-D of advances in tokamak science involving tokamak divertors, increases in stored plasma energy, and other key issues.
- Responsibility and participation in significant science and technology on TPX including physics analysis, construction of major subsystems, and important diagnostics.
- Impact of computational modeling on fusion understanding and experimental advances.
- Evaluation of exploratory concepts to a thorough and convincing extent.

- Responsibility for significant engineering design and R&D for ITER.

Fission Energy and Systems Safety

Situation

Anticipated growth in worldwide energy demands will stimulate demand for additional baseload generation. The environmental impact of fossil fuels should favor the use of technologies with low environmental impact such as nuclear power. LLNL has more than 60 projects related to fission energy and a broad range of nuclear system design, production, utilization, disposal, and safety analysis projects. With nearly 20 years of experience in systems technology, safety engineering, and licensing, we are positioned as an objective and technically respected intermediary among the power industry, regulatory agencies, and public institutions.

Vision

We will apply LLNL's multidisciplinary engineering and scientific capabilities to all aspects of fission energy utilization, including disposal. These activities will maintain and enhance our ability to respond to important national interests in reactor safety as well as in all elements of the nuclear fuel cycle—from fuel production to the final disposal of radioactive waste.

Goals

Our goal is to maintain a key role in all aspects of fission energy. The Fission Energy and Systems Safety Program's strengths in nuclear fuel repository development, nuclear waste management, fuel cycle improvement, and nuclear plant safety issues will position LLNL as a key organization to provide guidance and support to future national and international fission energy programs.

Issues

Several key issues face fission energy in general and the FESSP program in particular. Globally, the hurdles to fission energy acceptance, in addition to economic considerations, are:

- Safety
- Waste management
- Nonproliferation

FESSP's efforts focus on these issues. Given the disparate use of fission energy worldwide (e.g., France meets more than 70% of its electrical needs with fission energy), there is also an element of education required for public acceptance in the United States. These issues represent significant hurdles to broader acceptance of fission energy and must be addressed. These global hurdles are complicated domestically by U.S. policy that prohibits the recycling of spent nuclear fuel and by retrenchment regarding advanced fission energy research and development.

Strategies

FESSP continues to identify the root causes of engineering and safety issues that concern various U.S. government agencies involved with nuclear and nonnuclear facilities; to propose the development of methodologies and strategies for studying and resolving these issues; and to transfer and implement advanced engineering and safety technologies to those agencies.

We will work with DOE to establish a mechanism to work cooperatively with other federal agencies, private industry, and foreign countries; to streamline the process of formalizing agreements with industry so that we can be more attractive to industrial partners; and to identify areas where DOE interoffice coordination is needed to foster the development of new capabilities.

Success Indicators

We are committed to serving the national interests in addressing fission energy, systems engineering, and safety issues. Key success indicators include:

- Increased responsibility in implementing a suitable nuclear waste repository for the United States.
- Assistance in the disposition of nuclear material from both U.S. and former Soviet Union warheads.
- Increasing safe utilization of fission energy and involvement with next-generation advanced fission reactors.
- The use of risk assessment techniques in promulgating ES&H policies and regulations.
- Extending deployment of LLNL's Argus security system across the DOE complex.

Energy, Manufacturing, and Transportation Technologies

Situation

Energy, manufacturing, and transportation problems and their impact on U.S. economic competitiveness are major concerns at state and national levels. We formed the Energy, Manufacturing, and Transportation Technologies (EMATT) Program to explore areas where LLNL-developed technology can contribute innovative solutions to transportation and related manufacturing technologies. Our intent is to work with industry in solving national problems that are beyond the scope of industry alone.

Vision

We are challenged to develop energy, manufacturing, and transportation technologies that can stimulate economic growth and improve the competitiveness of U.S. industry in the global market while not adversely affecting the environment.

Goals

- In manufacturing, we intend to develop manufacturing technologies critical to U.S. industrial competitiveness by focusing LLNL resources and expertise and to provide manufacturing engineering support

to the DOE production complex.

Manufacturing-related projects can be grouped into the following technology areas: design, analysis, and characterization of machine tools; advanced materials and manufacturing processes; computer modeling of manufacturing processes; testing, inspection, and nondestructive evaluation; and education and training.

- In materials, our goal is to develop novel materials and processing tools to a maturity suitable for deployment in manufacturing. Our work spans the range of materials from metal composites and lightweight metals to fiber composites and organic adhesives.

Many projects include a strong three-dimensional process modeling component, with experiments to benchmark simulation predictions. Materials also cut across other work in energy and transportation.

Improved materials processing, materials performance assessment and life-cycle analysis, and process numerical simulation are necessary tools to enable the large-scale manufacturability of materials and to provide cornerstones for portions of the DP ADAPT and ASCI programs.

- In energy production, our goal is to reduce U.S. reliance on imported fossil fuels by simultaneously enhancing our domestic production capability for fossil and alternative fuels and improving the efficiency of using those fuels, particularly in the transportation sector.

- In transportation, we will develop new technologies to drastically reduce emissions from the transportation sector, such as advanced batteries and hydrogen-fuel capability for vehicles.

Strategies

Our strategy is to develop partnerships with DOE, other government agencies, and industry to enhance our ability to create relevant technologies and accelerate their usage in the marketplace. A particularly useful approach is to find high-value entry-level products and to refine the technology for subsequent introduction into the mass market.

- In energy production, we seek better ways to find, produce, and refine domestic petroleum through industrial partnerships funded by the Natural Gas and Oil Technology Partnership. We use computational modeling to maximize the efficiency of fossil fuels and to minimize emissions. Other objectives are to expand our oil-and-gas-production work into deepwater technologies and to develop strong participation in the DOE Industries of the Future program. We will also work to enhance the production of geothermal energy and to develop new stationary energy storage devices such as flywheels, zinc/air batteries, and aerocapacitors.
- In transportation, we seek new aerogel catalysts to further reduce emissions. We also emphasize alternatives to gasoline internal-combustion engines, such as hydrogen vehicles, refuelable zinc/air batteries, and hybrid vehicles containing small electromechanical batteries or carbon-aerogel-based supercapacitors for peak power. All of these will benefit DOE and DoD by continuing to reduce our reliance on imported fossil fuels and to improve efficiency and will be well suited to rugged high-voltage applications.
- In manufacturing, we intend to work with DOE's Defense Programs to integrate the past Technology Transfer Initiatives (TTI) manufacturing thrust of maintaining and enhancing DP manufacturing capabilities into the current Advanced Design and Production Technology (ADAPT) initiative. We will identify, develop, and leverage advanced technologies to stimulate and deploy leap-frog advances in manufacturing technologies to enhance near-term U.S. competitiveness.
- We will continue to develop materials with improved performance through control of microstructure and nanostructure. The cost-effective manufacture of such materials will be guided by increasingly sophisticated process simulation tools. Increasingly sophisticated characterization is necessary to

characterize performance relative to structure and process-induced variations and to assess long-term durability under realistic service environments. This strategy will not only provide superior and manufacturable materials necessary for implementing many of the objectives of the other EMATT programs but will also contribute directly to ADAPT, ASCI, and stockpile-surveillance requirements.

Success Indicators

We will consider our efforts to be highly successful if we can develop several new industrial partnerships each year.

- In energy resources, we intend to improve the technologies for producing economically competitive and environmentally acceptable transportation fuels. We hope to expand our role in the Industries of the Future Program in DOE/EE, the heavy oil upgrading and deepwater production activities in DOE/FE, maintain our strong participation in the Advanced Computational Technology Initiative, and expand our program in energy storage and distributed utility systems.
- In transportation, we are developing and applying defense technologies from many scientific areas to create a new generation of hybrid vehicles. The ultimate intent is that these vehicles be completely recyclable and operate at near-zero emissions using a variety of fuels.
- In materials manufacturability, our success will be measured by the improvement in performance and cost-effectiveness resulting from the introduction of new materials and processing tools into a variety of commercial and defense applications. The ultimate goal is to enable the completion of major national objectives through the use of improved materials and processing models.

Alternative and Advanced Energy Programs

Situation

Achieving energy security is essential to our economic health and to maintaining national security. We need to develop energy technologies that can provide reliable energy supply, stimulate economic growth, and improve U.S. industrial competitiveness without adversely affecting the environment. These technologies must be addressed within the current context of increasing U.S. reliance on imported crude oil, accompanying strains on military security and the balance-of-payments deficit, and increasing concerns about the long-term environmental effects of fossil-fuel use.

Goal

Our goal is to keep reducing U.S. reliance on imported fossil fuels by simultaneously enhancing the domestic production capability of fossil and alternative fuels and improving the efficiency of using those fuels, particularly in transportation. We will develop new technologies to drastically reduce emissions from the transportation sector, such as vehicles powered by advanced batteries or that have hydrogen-fuel capability.

Issues

- Can LLNL define programs for working effectively in partnership with industry?
- Will industry adopt LLNL-designed-and-tested components for use in advanced vehicles and energy systems?

- Is public knowledge sufficient about energy issues to support R&D?
- Will U.S. energy technology be competitive on the global stage of the future?

Strategies

Our strategy is to develop partnerships between DOE and industry for creating relevant technologies.

In the transportation area, special emphasis is placed on alternatives to gasoline internal-combustion engines, such as hydrogen-fueled vehicles and hybrid vehicles that contain small electromechanical batteries or carbon-aerogel-based supercapacitors for peak power. The hydrogen vehicle program uses an integrated systems approach to solve hydrogen production, storage, transportation, and use issues. We are playing a major role in the design of a hybrid-electric vehicle for the Partnership for a New Generation of Vehicles (PNGV).

We seek to improve the technology for producing geothermal energy; and we view near-term, high-value markets such as improved road asphalt as a way of maintaining shale oil as a viable future fuel option.

Success Indicators

We will consider our efforts highly successful if we can develop several new industrial partnerships each year, and if we can bring one major innovation of energy technology to the commercial marketplace each year.

Work for Department of Energy Sponsors

Assistant Secretary for Defense Programs

Technical Support Related to Safety

We are providing technical support in a number of areas relating to nuclear and facility safety by:

- Participating in development and review of DOE/DP's ES&H Management Plan.
- Supporting the NEPA compliance officer in preparing or reviewing Environmental Assessments and Impact Statements.
- Conducting transportation risk analyses and accident analyses.
- Preparing Environmental Assessment for the transportation of highly enriched uranium and low-enriched uranium from sites across the DOE complex to the Y-12 plant for processing and interim storage.
- Modernizing the DOE system for controlling visitor authorization to nuclear weapons data and integrating the database with the modernized personnel security databases.
- Providing safety analysis and risk assessment support for DOE's DP facilities.
- Developing software for preparing seismic hazard maps for the eastern United States.
- Developing guidelines for system qualifications related to ground shaking.
- Developing a clearinghouse of data, codes, and documentation of our studies in the areas of natural phenomena hazards for use by external clients. (This work is jointly funded by the Nuclear Regulatory Commission.)
- Supporting the implementation of the Laboratory Integrated Prioritization System (LIPS) in DOE facilities to improve the budgeting for ES&H activities. (This work performed through LANL).

- Providing safety oversight support for nuclear explosives operations.
- Providing criticality safety benchmarks to support DP facility operations.

Technology Transfer Initiatives (TTI)

LLNL has initiated more than 100 partnerships with private companies—partnerships intended to aid U.S. industry in enhancing global manufacturing competitiveness. The manufacturing projects can be grouped as follows: (1) design, analysis, and characterization of machine tools; (2) advanced materials and manufacturing processes; (3) computer modeling of manufacturing processes; (4) testing, inspection, and nondestructive evaluation; and (5) education and training.

We intend to develop manufacturing technologies critical to U.S. industrial competitiveness by focusing LLNL resources and expertise and by providing manufacturing engineering support to the DOE production complex.

Recent accomplishments

- FY95 budget: ~\$30 million (EMATT alone) through CRADAs, WFOs, Small Business Initiatives.
- Coordinated one of the first efforts in the DOE complex to work on precompetitive technology with industry and successfully implemented the project called TEAM (Technologies Enabling Agile Manufacturing).
- Successfully completed LLNL's first CRADA with industry.
- Implemented and managed one of the largest and most successful partnerships with Cincinnati Milacron, a 3-year, \$8 million agreement.
- Completed the first CRADA within the DOE complex to receive an R&D 100 award.

- Finalized a significant partnership with ICON Industrial Controls, Inc. which brings \$4 million per year for 3 years to LLNL.
- Received designation of B432 (The Livermore Center for Advanced Manufacturing and Productivity) as LLNL's first Technology Deployment Center/User Facility.
- Actively participated in the effort to establish a Northern California Manufacturing Extension Center; proposal to be submitted in 1995 to the TRP.
- Working with the NSF to establish an Engineering Research Center in precision manufacturing.
- Extended codes of fundamental importance to national security—three-dimensional codes developed in DP but applied to resin transfer, casting, and materials forming—to applications in materials processing in the commercial sector.
- Developed, in a CRADA with Kaiser Aluminum, the superplastic properties of 7000 series aluminum for aerospace applications—and also a more scientific understanding of what allows a material to behave in a superplastic way.
- Used our knowledge of catalysts and aerogels to develop a new catalytic converter for the USCAR initiative, which illustrates the cross-cutting nature of materials to specific programmatic objectives.

Objectives for the next few years

We will work with DOE/DP to integrate the past TTI manufacturing thrust of maintaining and enhancing DP manufacturing capabilities into the current Advanced Design and Production Technology (ADAPT) initiative.

In manufacturing, we intend to identify, develop, and leverage advanced technologies to stimulate and deploy leap-frog advances in manufacturing technologies to enhance near-term U.S. economic competitiveness.

We are using the LLNL base technology in the deposition of multilayer thin films to

demonstrate the feasibility of making structural materials with unique and heretofore unavailable properties. The ultimate goal is to use control of structure at the atomic level in a large-scale, manufacturable process to insert cost-effective, unique materials into practical applications. For example, nano-engineered materials are finding applications in areas such as thermal barriers for turbine blades, coatings for precision tool bits, and the construction of ultra-high-energy density capacitors for energy storage.

Office of Nonproliferation and National Security

Office of Security Affairs

Electronic Systems for Safeguards and Security

- We are developing an integrated system for the electronic transfer of personnel security data between DOE offices and the Office of Personnel Management. The goal is to reduce the time required to process DOE security clearances and to increase productivity.
- We are developing modernized, integrated databases for personnel security. The goals are to integrate these databases with the processing of security clearances, to eliminate redundancies, and to provide the infrastructure for complex-wide access control.
- We are developing a complex-wide automated access control system to permit the use of DOE standard badges in access control systems throughout the DOE complex.
- We are developing an approach to evaluating the security of the computerized systems that account for nuclear materials. The goal is to reduce the risk that such systems could be used to cover up the theft of nuclear materials.

- As a Martin Marietta CRADA team, we are working with the Argus software development team to develop and test the features needed for a commercial access security system based on the LLNL-developed Argus system.

Office of Arms Control and Nonproliferation

Safeguards and Security Planning for Protection of Russian Material

We are developing training classes and other materials to transfer to Russia the methods and technology used by the United States in managing the security of nuclear facilities. The goal is to improve Russian safeguards and security methods.

Office of Energy Research

Office of Fusion Energy

Tokamak Physics Experiment

A national team led by LLNL developed a preconceptual design for a steady-state advanced tokamak that was selected as the design basis for the Tokamak Physics Experiment (TPX) to be constructed at Princeton Plasma Physics Laboratory. We have a major role in the design and construction of TPX, especially on the design, development, and fabrication of the superconducting magnet system, external vacuum vessel (cryostat), and cryogenic system.

Recent accomplishments

- Completed the conceptual design review.
- Performed the preliminary design with magnet contractors.
- Oversaw industrial development of superconducting strands.
- Developed practice conductor.

Collaboration on DIII-D

A strong team of LLNL scientists, engineers, and technicians is collaborating on the DIII-D tokamak at the General Atomics (GA) laboratory in San Diego,

California. We focus on edge and divertor physics and on advanced tokamak issues. Edge physics behavior determines the character of the power flow from the confined plasma to the divertor, a problem area for fusion. Advanced tokamak physics has a large leverage on the tokamak reactor's performance.

Recent accomplishments

- Installed new diagnostics, including a Thomson Scattering System, in the divertor area.
- Participated in edge physics experiments on DIII-D.
- Provided project management for the radiative divertor program (RDP).
- Worked to improve the numerical codes used to analyze DIII-D data and to guide the design of the RDP.

International Thermonuclear Experimental Reactor (ITER)

ITER is an international collaboration—among the European Community, Japan, Russia, and the United States—for a 1500-MW (thermal) experimental fusion reactor. We provide personnel to the Joint Central Team and the U.S. Home Team, including the Home Team Engineering Manager, and we perform R&D tasks for critical technologies.

Recent accomplishments

- Assumed lead for the materials properties handbook, the interim structural design criteria, and assembly tasks.
- Developed advanced scenarios that allow steady-state operation at full fusion power.
- Optimized the poloidal field system (in collaboration with ORNL), resulting in greater operational flexibility at reduced cost.
- Designed (in collaboration with GA) a plasma position and shape control system.
- Optimized (in collaboration with GA) electron cyclotron current drive scenarios.
- Tested Japanese full-scale conductor.
- Established a process for chromium plating of superconductor strands for both ITER and TPX.

- Provided electromagnetic, structural, and thermal analysis for ITER model coil effort in U.S.

Advanced Fusion Assessment Program

We perform conceptual studies and modeling of novel or relatively unexplored ideas for advanced fusion reactors, focusing on both the underlying physics and the ultimate reactor potential. We seek, generate, and evaluate ideas for fusion reactor concepts that have potential for a step improvement in cost, complexity, and development path over the current, conventional concepts.

Recent accomplishments

- Conceived a novel method of nonthermonuclear fusion— “Shape Enhanced Fusion” —with an order-of-magnitude increase in the cross section for some advanced fusion fuels.
- Re-evaluated data from previous spheromak experiments and demonstrated energy confinement times consistent with magnetic turbulence.
- Analyzed a new magnetic fast ignition for inertial confinement fusion (ICF) that should increase the gain from an ICF target by a factor of 10.
- Designed a compact, high-power-density fusion neutron source based on a continuous flow pinch.

MFE Theory and Computations

Our activities include (1) theoretical and computational research on the physics of the open-field-line scrape-off layer (SOL) at the edge of a tokamak, (2) gyrokinetic simulation of turbulence-induced transport in plasmas, (3) development of Corsica, a comprehensive simulation of a toroidal magnetic fusion device; and (4) theoretical computational modeling of plasma diagnostics. The goal is to develop understanding of phenomena observed in present experiments and to develop predictive capabilities that will enable us to optimally design future devices.

Recent accomplishments

- Studied the parameter dependences of ion-temperature-gradient-driven turbulence in tokamaks and compared with fluid simulations and experimental data. Also developed massively parallel version of code.
- Developed models for SOL turbulent transport and role of drifts in producing asymmetries and altering boundary conditions in SOL; these are being incorporated into our UEDGE code, a major tool for understanding and controlling the intense heat fluxes hitting the surfaces bounding a tokamak.
- Developed demonstration codes coupling turbulence simulation to a plasma transport code and coupling core and edge-region transport codes as part of the Corsica project; the previously released version of Corsica is now regularly used for modeling DIII-D and ITER.
- Developed a multidimensional theory of electromagnetic wave propagation, reflection, and scattering by density fluctuations in a spatially nonuniform plasma. A suite of new computer codes has improved the understanding of wave reflectometry, an important diagnostic to measure plasma profiles and fluctuation characteristics.

Assistant Secretary for Environment, Safety, and Health

Office of Nuclear Safety Policy and Standards

Natural Phenomena Hazards Policy and Standards

We provide technical support for the development of DOE orders and standards related to natural phenomena hazards. We also help DOE develop guidance on computer use in safety-critical and environmentally-critical applications.

Deputy Assistant Secretary for Nuclear Facility Safety

Packaging and Transportation Technical Support

We have provided technical assistance to the Packaging and Transportation Division related to the safety of packaging and transporting radioactive materials. We have performed assessments; supported the development of policies, standards, and orders; and developed training.

Office of Nuclear Energy

We provide a broad spectrum of environmental and safety support to the Office of Uranium Programs. We are currently performing engineering and cost analyses for the selection of a long-term management strategy for depleted uranium hexafluoride. We support DOE's nuclear safety upgrade program at the gaseous diffusion uranium enrichment plants. LLNL scientists and engineers are assisting the Department in developing and implementing transparency measures for the purchase of 500 metric tons of highly enriched uranium from the former Soviet Union.

Office of Civilian Radioactive Waste Management

Yucca Mountain Project

Disposal of civilian and defense high-level nuclear waste and spent nuclear fuel is assigned by federal statute to OCRWM, which funds research for nuclear waste programs. In response to Congressional inquiries and DOE desires to minimize the number of contractors at the Yucca Mountain characterization site, LLNL has joined as a partner with the prime Management and Operating contractor, TRW. As a partner, we are participating in

studies for a potential nuclear waste repository at Yucca Mountain, Nevada. Our programmatic responsibility is to concentrate on the engineered barrier system (EBS), which includes the container to hold the waste and interactions with its immediate environment. The partnership with TRW, and by extension support to OCRWM, is in excess of \$18 million dollars in FY95.

The major elements of the program are:

- Defining the physical and chemical environment in which the waste packages must function.
- Selecting materials and preparing design specifications for the waste containers.
- Characterizing the behavior of waste materials in the repository environment.
- Developing mathematical models and computer codes for predicting the long-term function and durability of these systems.

Our recent focus has been on site characterization and repository-performance issues. LLNL has provided conceptual and technical support for an emplacement strategy referred to as "extended dry out." This approach envisions using the heat from the decaying waste to drive moisture from the repository. By enhancing the natural system's performance, container corrosion and the most credible transport mechanism for radionuclides would be eliminated. LLNL is developing conceptual models, computer codes, laboratory experiments, and field tests to demonstrate the validity of the "extended dry out" concept.

Our strategy focuses on developing, assessing the effectiveness of, and documenting a design for a waste package that meets the performance requirements of 10 CFR 60. The EBS design will continue to evolve as we obtain data from site characterization and as we complete more detailed phases of design.

Assistant Secretary for Fossil Energy

Fossil Energy Projects

The Energy Technologies program of EMATT covers all aspects of producing and distributing fossil and alternative energies. The total FY95 budget of about \$8M includes funding from the DOE offices of FE, DP, and ER, as well as DoD and private industry. The largest component of the program relates to producing conventional oil and gas. This work area attained a substantial increase in funding through the Advanced Computational Technology Initiative with six new projects with the oil and gas industry funded by the DP-TTI program through a competitive process involving a ranking by an industry review panel. The largest project involves developing a prototype system for handling California and Texas oil and gas production data. The other projects include an improved method for converting oil well log data to digital form, a better understanding of the physics of well perforation, improvements in completion technology for natural gas storage, the design of shaped charges as seismic sources, and deterministic modeling of neutron well logging. We also have smaller activities in heavy oil upgrading and in converting natural gas to methanol.

Recent accomplishments

- Used cross-well electromagnetic imaging to image the steam plume formed during thermal recovery of California heavy oil.
- Identified chemical agents that can extract metals from heavy crude oils.

Office of Fissile Materials Disposition

Safeguards and Security of Nuclear Materials Disposition

We provide support to the PEIS for the secure disposition of excess weapons

nuclear material, and we are developing analysis for the decision related to which disposition approach to follow.

Assistant Secretary for Energy Efficiency and Renewable Energy

Hydrogen Production from Municipal Solid Waste

We are developing a cost-effective, commercial, hydrothermal process for gasifying municipal solid waste to produce hydrogen for use as a transportation fuel, working with Texaco on this project.

Hydrogen Storage in Engineered Microspheres

We are developing glass microspheres to use for the safe, economical bulk transport of hydrogen. Glass microspheres of 0.05–0.5 μm diameter with 1-micron-thick walls are heated to 200–400°C under hydrogen pressure to trap the hydrogen inside the microspheres at high pressure. The goal is to demonstrate hydrogen-to-microsphere mass fractions as high as 10% and a hydrogen bed density of 20 kg/m^3 .

Optimized Hydrogen-Fueled Internal Combustion Engine

We are modeling and designing a piston engine and generator that is the mechanical equivalent of the fuel cell. We are optimizing the engine for hybrid vehicles to use hydrogen or hydrogen/natural gas mixtures. The goal is to develop a hydrogen-fueled engine with greater than 45% brake thermal efficiency and with NO_x emissions less than 100 ppm. We have also developed a hybrid vehicle evaluation code, and we have delivered an optimized engine cylinder head to Sandia, California, for testing.

Chemical Kinetic Modeling of Hydrogen Applications

We are developing the detailed chemical kinetics of fuel oxidation and NO_x and pollutant emissions in zero or one-dimensional formulations. We are identifying the most important subscale processes in the combustion of hydrogen and hydrogen/natural gas mixtures. The goal is to simplify the detailed combustion kinetics for use in multidimensional fluids mechanics codes used for engine combustion modeling.

Hydrogen Infrastructure Studies

We are studying the state—and the costs—of technologies that could facilitate the introduction of hydrogen as a transportation fuel. These technologies are for small-scale production, distribution, storage, and transfer to the vehicle system. We have shown that:

- Used in an advanced hybrid-electric vehicle, the cost of hydrogen fuel per mile made by steam reforming of natural gas and distributed to small fleets would be about one-half the fuel cost per mile of gasoline in today's average car.
- The fuel costs for advanced hybrid-electric cars fueled with liquid hydrogen at today's delivered costs are about the same as for today's average gasoline vehicle.

Low-Temperature Solid Oxide Fuel Cell

We are using advanced vapor deposition techniques to develop pinhole-free multilayer solid oxide fuel cells. By producing high-quality layers of 0.1–1.0 micron thickness, the operational temperatures can be reduced from 1100°C to 450–650°C. We have completed the first cell using a yttrium-stabilized zirconia layer of 1 micron thickness.

Industrial Sector Work

We are participating in a multilab effort to develop a Refinery of the Future (ROF) Initiative. This effort would focus on

downstream activities in the petroleum refinery industry and be in collaboration with appropriate industrial organizations (e.g., National Petroleum Refinery Association and the American Petroleum Institute). The primary areas of interest to the industry are environmental analysis, modeling, and processing. Particular expertise evidenced at LLNL includes site characterization, atmospheric and hydrology modeling, chemical process modeling, catalysts, combustion modeling, and new materials.

We have just concluded a major program in developing the superplastic properties of ultrahigh carbon steels. This technology provided a means of fabricating near-net-shape components of highly wear-resistant steels. Future work under consideration involves focusing on specific potential applications of the generic process with respect to composition and fabrication.

Geothermal Resource Recovery

We are using x-ray computed tomography on well cores to measure the geothermal resources at The Geysers (California), which produces 1500 MW of electrical power. We also seek to improve the technology for producing geothermal energy.

Combustion Modeling

We have developed and tested a computer model for analyzing the combustion in industrial burners and have applied that model to the problem of reducing the emissions of NO_x and unburned hydrocarbon and volatile organic compounds. Our model will make it possible to design economical burners that comply with the Clean Air Act.

Assistant Secretary for Policy, Planning, and Program Evaluation

Assessments of the Potential of Energy Technologies

LLNL performs technical analysis to provide DOE with assessments of the potential of various energy technologies to impact the strategic goals of the United States. The goal is to identify the most important technologies in energy R&D. LLNL will establish criteria for assessment and establish an expert panel to objectively perform the assessments.

Other DOE—Field Offices and Other Laboratories

Pantex Plant—Security Systems Upgrades

We are providing a variant of the LLNL-developed Argus system, designed to provide the necessary access control, intrusion detection, and alarms for Pantex's plant-wide security system. We are providing all of the design, modifications, procurement, and installation of the central computers, displays, and network communication hardware and Argus software. Positive Personnel Identification

and Verification has been added to our scope of work.

Idaho National Engineering Laboratory—Electronic Security Systems

We are providing software and hardware to prepare the Idaho Chemical Processing Plant for future conversion to the Argus security system. We are also assisting in the conceptual design of INEL's Personnel Access Control and Security Enhancement System.

Nuclear Criticality Safety Support to Oak Ridge Field Office

We have assembled a team of criticality safety professionals to provide support to the Portsmouth Diffusion Plant.

Safeguards and Security Support to Savannah River Operations Office

We have developed and evaluated advanced approaches for analyzing safeguards and security at the Savannah River Site. We have demonstrated a virtual reality model of safeguards and security measures.

Technical Support to Albuquerque Operations Office

We support the Nuclear Explosives Safety Division in reviewing activities related to the transportation of radioactive materials within the DOE complex.

Work for Department of Defense Sponsors

Ballistic Missile Defense Organization

National Test Facility Security System Upgrades

We are producing and supporting the hardware and software required for operating the Argus security system at the NTF. Other work includes researching retrofits for a swipe badge reader to accommodate the new Air Force standard

badges and upgrading existing computer systems to support Argus.

Optics Work

- We operated the Large Optics Diamond Turning Machine (LODTM) for the DoD-BMDO program.
- We recently completed the construction of two lightweight beryllium mirrors for the Keck astronomical telescope in Hawaii. The telescope construction is a joint California Institute of Technology and University of California project. Our LODTM was the only machine tool capable of fabricating these highly precise mirrors.

- In conjunction with the BMDO-Alpha Chemical Laser Program, we successfully machined and delivered to TRW an Annular Optical Prototype that demonstrated the viability of directly machining large single-crystal silicon optics.

Office of Naval Research

Kara Sea/Russian Naval Waste Assessment

We provide vulnerability and safety assessments of the Arctic/Pacific Ocean environment concerning the nuclear waste generated and disposed of by the Russian naval program.

Work for Other Federal and State Programs

Federal Aviation Agency

Human Factors in Security

To enhance airport security, we are developing functional requirements and explosive simulates for the next generation of security screening devices.

U.S. Geological Survey

Yucca Mountain Seismic Design Criteria

We provide technical assistance in developing guidelines for seismic criteria for repositories.

Nuclear Regulatory Commission

Support to Office of Nuclear Materials Safety and Safeguards

We are providing technical support in a number of areas:

- Working with the NRC staff to provide the nuclear regulatory authority in Ukraine with information needed for establishing regulatory control over radioactive wastes and spent nuclear reactor fuel.
- Reviewing DOE/RW activities relative to changing the NRC's methods for evaluating the criticality safety of a spent fuel transport cask.
- Providing expert technical assistance to resolve issues related to transporting spent nuclear fuels and other radioactive materials.
- Developing input for resolving new issues that arise during the review of Safety Analysis Reports on the storage of spent nuclear fuel.
- Developing a process to analyze the risks in the use of radiation-emitting devices and applying this process to the gamma knife, a gamma-irradiation device used for intracranial lesions.
- Assisting with the reviews of quality management plans at medical facilities.
- Providing technical assistance in the review of uranium mill tailings remediation

plans, evaluation of radon barrier adequacy, and pile seismic stability.

Support to Office of Nuclear Reactor Regulation

Our technical assistance includes:

- Assisting with the evaluation of civil, structural, seismic, electrical, and instrumentation and control systems of Advanced Light Water Reactors. The work includes recommending acceptance criteria for advanced design features.
- Performing sensitivity analyses for 10 nuclear power plant sites, which includes deaggregating the seismic hazard results to determine the controlling earthquake's magnitude and distance for each site.
- Assembling data and developing technical positions as preparation for the revised geologic and seismic siting criteria for nuclear power plants.
- Providing data and expertise for the review of seismic design criteria for the new generation of nuclear reactors.

Support to Office of Nuclear Regulatory Research

Our work includes:

- Evaluating the existing probabilistic hazard methodologies and defining a state-of-the-art methodology for future use.
- Providing technical support for the review of Individual Plant Examination of External Events submittals from utility companies.
- Providing guidance for industry standards related to the development of safety-critical software for nuclear power plants.

Information Technologies

We have established a Nuclear Systems Safety Center (NSSC) to serve as an on-line national resource for information and analysis. The NSSC is linked via communications networks to regulatory agencies (including the NRC), to national laboratories, and to other parts of the technical community. As part of our

information security efforts, we have developed capability in implementing so-called firewalls to protect information systems from assault. Additionally, our information technology strengths contributed to bringing the Vice-President's National Performance Review office on-line on the Internet.

Federal Highway Administration

We are working with the FHWA and the National Highway Traffic Safety Administration to improve computational tools for designing roadside safety hardware. Our approach uses the DYNA/NIKE code to model barrier crashes and post-crash vehicle motions.

Under FHWA sponsorship we are addressing advanced traffic management systems and developing the WINTRANSYT code for use on desktop computers by traffic engineers.

We are developing new methods of ground-penetrating radar to rapidly assess earthquake damage to bridge structures and roadways. Work in this area is currently underway with FHWA, Caltrans, and the Oregon Department of Transportation.

California Department of Transportation

We have assisted Caltrans in defining a communications standard for Automatic Vehicle Identification for California. This standard has now been cast into law for electronic toll collection, and the technology is being applied to toll bridges as a first application.

We are also using electrical impedance tomography in roadway inspections to detect moisture penetration.

Partnership for a New Generation of Vehicles (PNGV)

We are an active participant in President Clinton's Partnership for a New Generation of Vehicles initiative. All projects involve close collaboration with other DOE laboratories and the "Big 3" U.S. automotive manufacturers. Current technology focus is on low emissions catalysis, NO_x sensors and systems (engine management) for diesel engines, advanced composite material modeling, design and optimization of cast light metals, supercomputing for advanced automotive component design, computational fluid dynamics (combustion analysis, drag reduction and under-the-hood thermal management), and superplastic forming of stainless steel. Expected future involvement will include energy storage (flywheel, fuel cells, and

aerocapacitors), and hybrid vehicle development and prototype demonstration.

Other Industrial Work

- We have successfully developed and tested a self-feeding zinc-particle electrode for a zinc/air battery. This increases energy storage capability and emergency reserve batteries by allowing external storage of the zinc reactants. An engineering prototype zinc/air battery has been developed and tested on an electric bus.
- We are developing an electromechanical battery based on the flywheel concept of energy storage. A working flywheel will be delivered to an industry partner in 1995.
- We have a CRADA with PowerOne and PolyStor to develop and commercialize aerocapacitors based on carbon aerogels for electronic and energy-storage applications. (Through TRP)
- We have a CRADA with Aerojet to commercialize silica aerogels for high-value insulation applications. (Through TRP)

Partnerships and Collaborations*

American Textile Partnership
Amoco Oil Co.
Argonne National Laboratory
Babcock and Wilcox
California Department of Transportation
California Institute of Technology
Calstart
Cincinnati Milacron
Caterpillar Inc.
Chrysler Corporation
Cummins Engine Company, Inc.
Federal Aviation Administration
Federal Highway Administration
Ford Motor Company
Gas Research Institute
General Atomics
General Motors Corporation
General Motors' Industrial Tools Inc.
ICON Industrial Controls Corp.
Kaiser Aluminum & Chemical Corporation
Ladish Co.
Lawrence Berkeley Laboratory
Los Alamos National Laboratory
Martin Marietta Information Systems
Massachusetts Institute of Technology

National Aeronautics and Space
Administration
National Highway Traffic Safety
Administration
North Star Steel
Nuclear Regulatory Commission
Oak Ridge National Laboratory
Oregon Department of Transportation
Princeton Plasma Physics Laboratory
Pratt & Whitney
Rohr Inc.
Sandia National Laboratories
Shimizu Corporation
Stanford University
Sutek Corp.
Texaco Inc.
Trinity Flywheel Batteries Inc.
TRW Inc.
University of California
U.S. Air Force
U.S. Department of Energy
Westinghouse Electric Corp.

**Partial list*

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